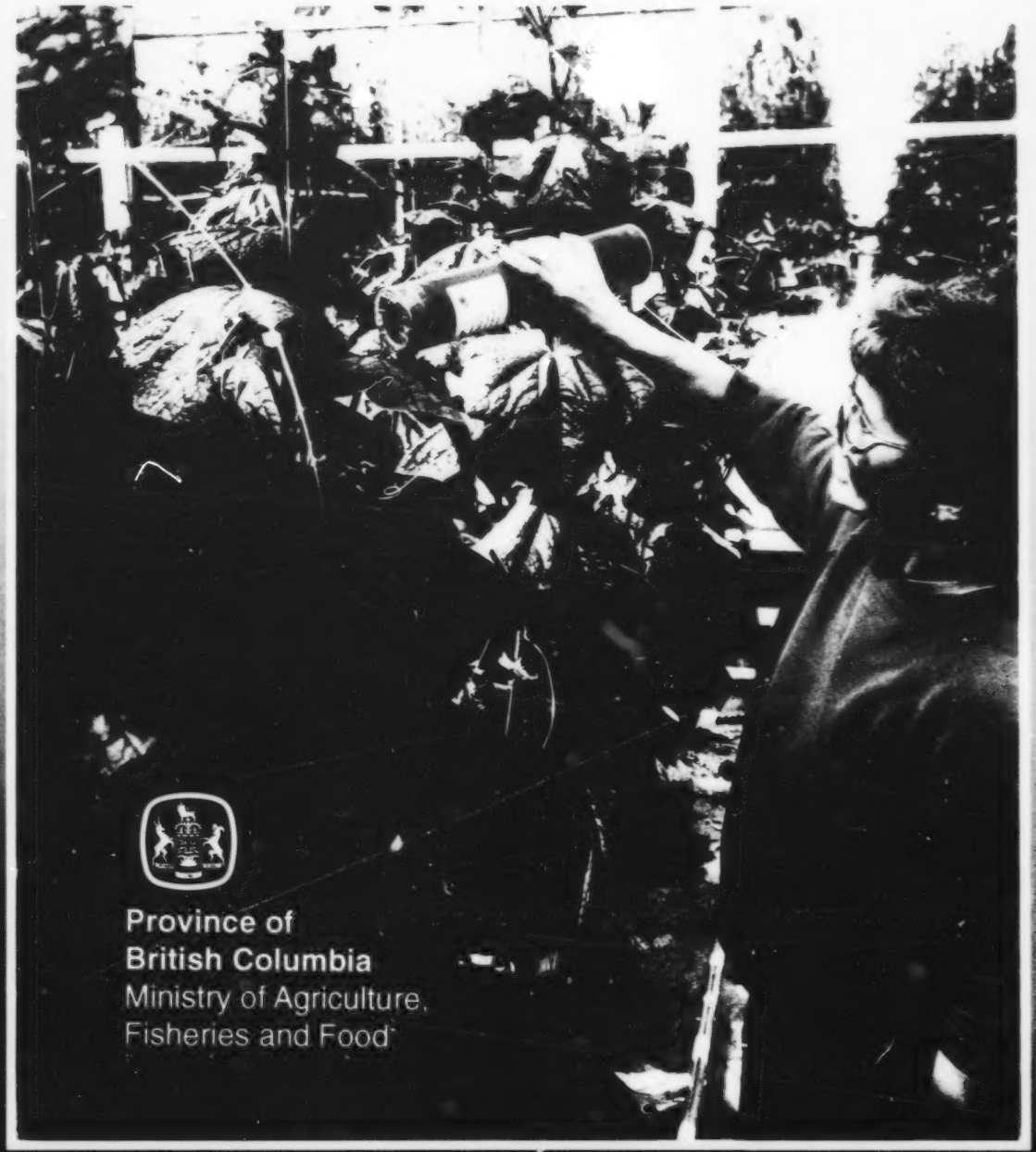
INTEGRATED CONTROL OF GREENHOUSE PESTS

FOR COMMERCIAL GROWERS



Province of
British Columbia
Ministry of Agriculture,
Fisheries and Food

Integrated Control of Greenhouse Pests

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INTRODUCTION

For many years after the development of synthetic pesticides, growers of greenhouse crops relied solely on chemicals to protect their plants from pests. However, increasing problems associated with chemical control methods, including phytotoxicity-induced yield reductions, decreased effectiveness due to the development of pest resistance, and legislated restrictions on pesticide availability have resulted in widespread reliance on biological control methods.

The use of wasps to control whiteflies was originally conceived over 60 years ago, but was eclipsed by the arrival of DDT and its relatives. During the 1970s this was revived and, along with predatory mites to control spider mites, developed as an effective control method in Holland, England and subsequently in North America.

The success of these programs stimulated further research and development, resulting in the availability of biocontrol agents for thrips, aphids, and fungus gnats.

Recognition of the importance of early detection and on-going population monitoring to the success of biological control programs has led to the development of greenhouse pest monitoring programs based largely on the use of yellow sticky traps.

Pest damage to greenhouse vegetable crops can be effectively and economically minimized through an integrated pest management (IPM) approach. This system utilizes chemical and biological controls, monitoring programs, and appropriate management practices relating to pruning and sanitation.

MONITORING

Successful IPM programs utilizing biological agents are based on early detection of pest populations and ongoing monitoring of pests and biological agents. This allows growers to act on the first appearance of pests and to determine if control agents have established and pest populations are being controlled.

Yellow sticky traps (fig. 1) may be used to detect and monitor populations of greenhouse whitefly, western flower thrips and onion thrips. Blue sticky traps are very effective for monitoring thrips, but do not attract other pests. Trap monitoring will usually detect greenhouse whitefly and thrips before they are noticed on the plants and well before they cause any apparent crop damage.

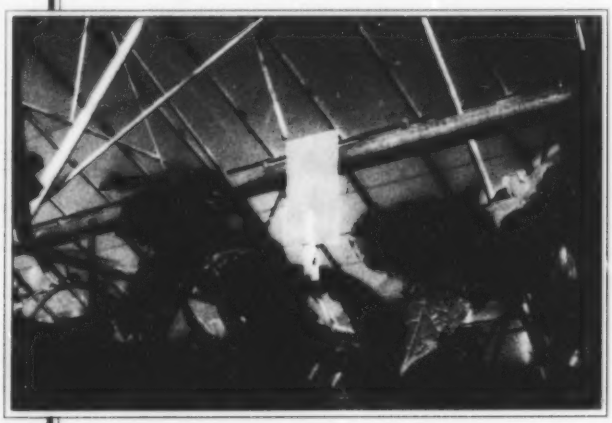

Figure 1: Yellow sticky insect monitoring trap.

A number of different traps are available. Trap choice depends mainly on cost and ease of handling. For tomatoes and peppers, the bottom of the trap should be level with the tops of the plants until the plant reaches the wire, after which it may be hung from the wire. On cucumbers, the middle of the trap should be level with the tops of the plants. Traps should be changed at least monthly, more often in hot weather as the glues become less effective.

For early detection of thrips or whitefly infestations, traps should be used at a density of at least one trap per 100 tomato or pepper plants, and one trap per 50 cucumber plants. Traps should be distributed evenly through the greenhouse, with extra traps located in areas of previous early infestations, such as near doorways, along alleyways or at the ends of rows. It is critical that the traps be checked at least once a week. Biological control programs should be initiated as soon as the first pest is detected. An on-going record should be kept of trap-catch numbers.

Two-spotted mites should be monitored by direct observation of the plants. As soon as the crop is in the greenhouse, plants should be checked for two-spotted mite feeding at least once a week. This can be done in conjunction with normal pruning and tying operations. It is essential that damage be detected in the early stages when predators will be most successful.

Aphids on peppers must also be monitored by direct observation of the plants in conjunction with normal pruning and tying operations. Lower leaves and growing tips should be examined.

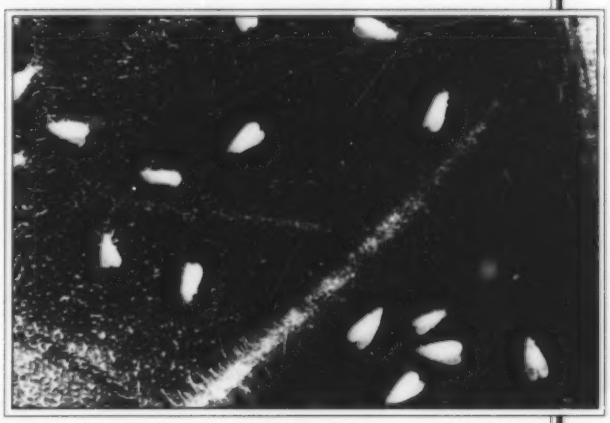

Figure 2: Whiteflies on a cucumber leaf.

Early detection allows timely initiation of control procedures. Ongoing monitoring is needed to determine the success of those procedures. This is particularly important for western flower thrips. Numbers of adult thrips should be noted on traps on a weekly basis. Once predators are introduced, weekly counts of immature thrips and predator mites are required. This is best done by rinsing the surface of leaves with water and catching the run-off in a 100 mesh sieve, then counting mites and thrips with the aid of a microscope. While it is possible for a grower to perform this monitoring, the process is time consuming and it is recommended that growers contract the services of a pest management consulting firm.

BIOLOGICAL CONTROL

Whiteflies

Whiteflies are among the most common pests in greenhouses. Cucumbers and tomatoes are readily attacked, as are many ornamental plants. Pepper plants are seldom attacked by whitefly. Adult whiteflies (fig. 2), powdery white and about 1.5 mm long, are found on the undersurface of leaves where they suck sap and lay pale yellow eggs. The eggs hatch in five to seven days to oval, flat, pale green nymphs or "scales" (fig. 3) that, after a brief period of mobility, remain in one place and feed on sap from the leaves. After two weeks the nymphs become pupae and about 10 days later the adult whiteflies emerge. The cycle from egg laying to adult emergence takes approximately four weeks (fig. 4).

Plants heavily infested with whiteflies are generally lacking in vigor and may wilt, turn yellow and die. The leaves and fruit become coated with a sticky substance secreted by the whiteflies called honeydew, which encourages a black fungal growth called "sooty mould" (fig. 5). As a result fruit must be cleaned, increasing labour costs and chance of damage. Also, the fungi on the leaves may reduce plant growth by lessening the amount of light reaching the leaf surface.

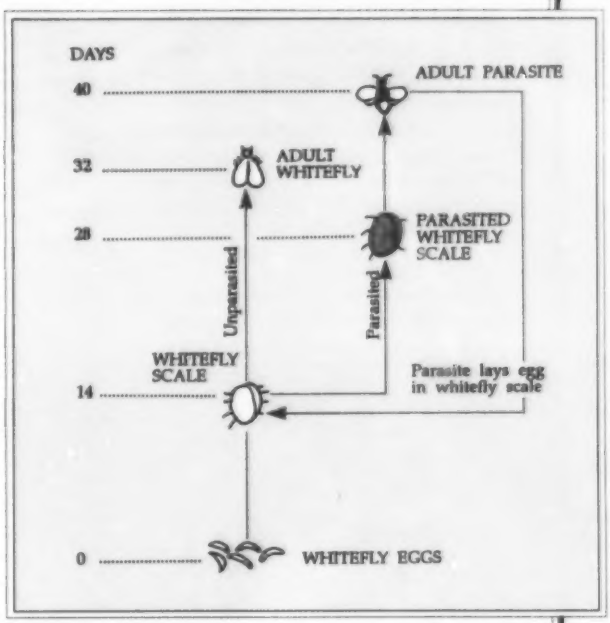

Figure 4: Life cycles of the greenhouse whitefly and its parasite *Encarsia formosa*.

Figure 3: Parasitized (black) and unparasitized whitefly nymphs, and adult whitefly and *E. formosa*.

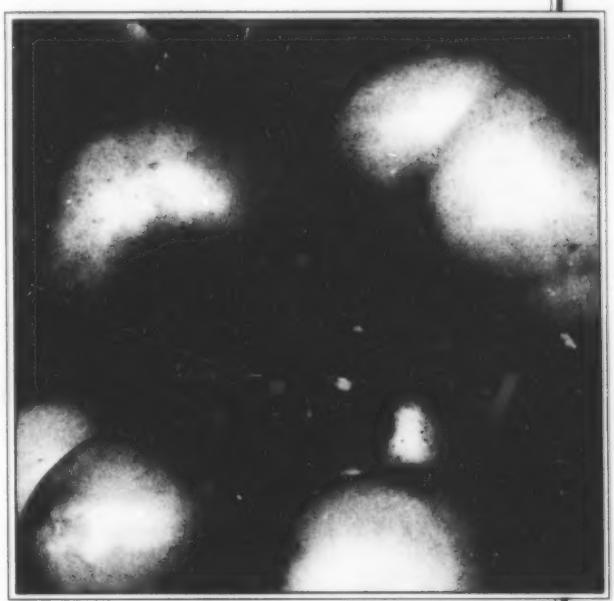

Figure 5: Tomatoes with "sooty mould" developing on whitefly secretions.

Two species of whitefly infest British Columbia greenhouse crops. The "greenhouse whitefly" *Trialeurodes vaporariorum* is most common. However the "sweet potato whitefly" *Bemesia tabaci*, introduced to Canada in recent years on imported plant material, has been found in some greenhouses. The immature stages of the two species appear similar, but the adults can be distinguished without magnification. The greenhouse whiteflies' wings are held horizontally, giving it a triangular appearance from above. The vertically-held wings of the sweet potato whitefly give it a tubular appearance from above (fig. 6). Because higher parasite release rates are needed for the sweet potato whitefly, growers should have whitefly identified by a government or private consultant.

Figure 6: Sweet potato whitefly adult.

Adult *Encarsia formosa*, the parasite used to control whiteflies, are about 0.6 mm long and have a black head and thorax and yellow abdomen (fig. 3). Almost all adults are females, each laying an egg in 50 to 100 whitefly scales. The parasite develops inside the scale, turning greenhouse whitefly scales black (fig. 3) and sweet potato whitefly scales light brown (fig. 7). When fully developed and ready to leave the scale, the new adult chews a small, round, exit hole (fig. 8) and begins searching for whitefly scales to parasitize. The complete cycle takes three to four weeks at normal greenhouse temperatures (fig. 4).

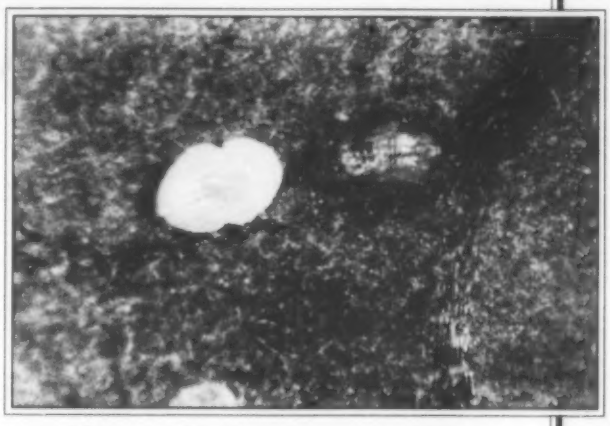

Figure 7: Parasitized (brown) and unparasitized sweet potato whitefly nymphs.

Figure 8: Adult exit hole in parasitized whitefly nymph.

Applying Whitefly Parasites

Light and temperature play an important role in the use of parasites for whitefly control. The parasite is most efficient under high light conditions and temperatures of 18 to 27°C. Introductions under lower light and temperature conditions can be successful only if parasites are introduced weekly before or as soon as the first whiteflies are detected. Best results are achieved with on-going releases of low numbers of parasites started when the first whitefly is detected on yellow sticky traps. Trap monitoring should begin when the crop is started.

Initial levels of whiteflies must be lower than one whitefly for every 10 plants for successful biological control. The parasite is harmed by most pesticides (Table I). A single application of a harmful chemical can prevent successful biological control for weeks or months. Some otherwise harmful pesticides can be applied in ways that reduce the hazard to biological control agents. Ground sprays are an example of this.

Figure 9: Paper card, with glued-on parasites, attached to tomato plant.

Parasites are distributed to growers in the form of parasitized (black) whitefly scales glued to cards. The cards are notched for easy attachment to leaf stems (fig. 9). A standard number of parasitized scales are concentrated in one area of the card to permit handling of the card without damage to the parasites.

Parasites should be applied as soon as possible after receipt. The package containing the parasites should be opened in the greenhouse where they are intended to be used to prevent loss of emerged adults.

Application rates are:

Tomatoes — 1 parasite for every 4 tomato plants introduced weekly for 9 weeks until 80% of all whitefly scales are parasitized.

Cucumbers — 1 parasite for every 2 cucumber plants introduced weekly for 9 weeks until 80% of all whitefly scales are parasitized.

Other Crops — Parasites are being used experimentally on other greenhouse crops that are attacked by whitefly. Contact bio-control suppliers for rates and recommendations.

Whitefly are often found grouped together on a few leaves or plants. If the parasite is controlling the whitefly, it will be difficult to find adult whitefly on plants after nine weeks of parasite introductions. Plants with low numbers (3-10) of whitefly should be spot-treated with thiodan or insecticidal soap. If higher numbers (10+) of whitefly adults or unparasitized scales are present together on leaves, contact your bio-control supplier before introducing more parasites.

Mites

The two-spotted spider mite *Tetranychus urticae*, also known as the red spider mite, feeds on over 200 species of plants and is universally one of the most serious pests of greenhouse grown cucumbers. It is named for the two dark spots present on the adult mite and the red hibernating phase present in the spring and fall (fig. 10).

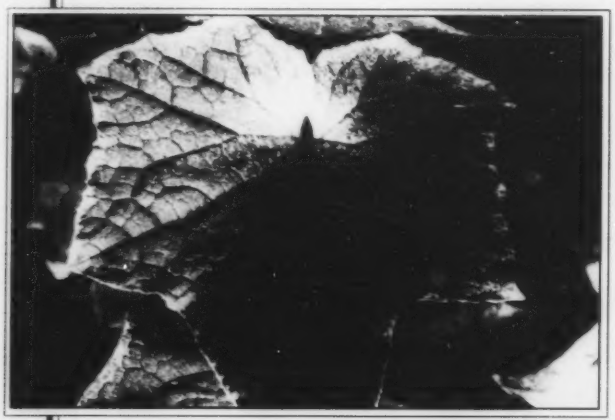

Fig. 10: Leaf with spotted and red phases of the two-spotted spider mite.

Plant damage occurs as the mite punctures the cells of the leaf, feeding on the plant fluids and causing areas of speckling on the leaves (fig. 11). Damage usually appears first at the base of the leaf (fig. 11) and spreads from the bottom to the top of the plant. In severe cases, the leaves become covered with a fine webbing, turn brown, and aggregations of migrating mites drop to adjacent plants on "ropes" of webbing. Plant vigor, and consequently yield, are reduced by heavy mite populations.

The number of generations of two-spotted mites is increased by warmer temperatures. At 21°C a generation is completed in two weeks (fig. 12). One female mite in one month can give rise to 20 offspring at 15°C, 13,000 at 21°C, and 13,000,000 at 27° C. Each female lays over 100 pearl-like eggs on the under surface of the leaves. Young mites appear as smaller versions of their parents, passing through three immature stages before becoming adults. In the fall, triggered by decreasing day lengths and temperatures, females change to a red colour and move into the cracks and crevices of the greenhouse to hibernate. As the days lengthen in the spring and heat

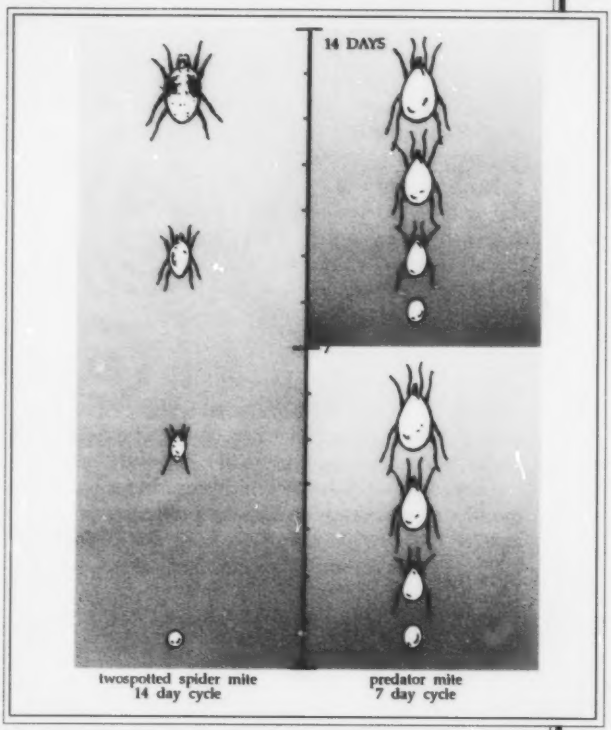

Fig. 12: Life cycle of two-spotted spider mite and its predator at 21°C.

returns, the still-red mites leave the hibernation sites and attack the new planting. They may also be reintroduced from winter crops or come into the greenhouse from outside plantings and weeds.

Adult *Phytoseiulus persimillis*, the predatory mites used to control two-spotted mites, are about the

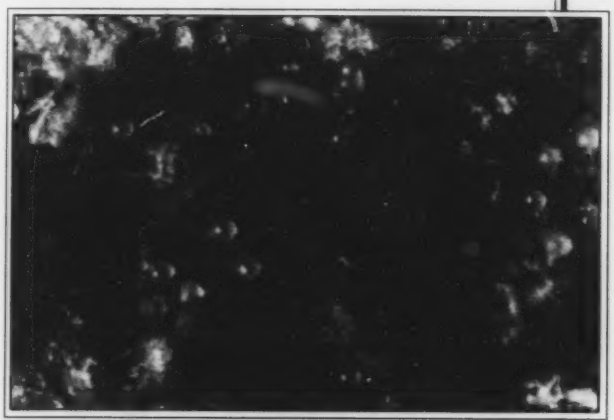

Fig. 11: Cucumber leaf with small area of speckling, indicating feeding by mites.

same size as their prey but can be distinguished by their bright orange-red colour, absence of spots and hair (fig. 13), and more rapid movement. They feed only on two-spotted spider mites and are harmless to people or plants.

Predatory mites reproduce best at temperatures between 21 - 27°C and humidities above 60%. Each female lays over 50 oval shaped eggs which hatch in a few days and pass through three immature stages in less than one week (fig. 12). This rapid rate of development enables predators to overtake the slower developing pest mite populations. They feed on all stages of two-spotted spider mites, killing 5 - 20 per day. Unlike the two-spotted mite, the predator does not hibernate and consequently dies when the host has been eliminated.

During the first month of the growing season when the plants are small and frequently handled, growers should watch carefully for signs of spider mite damage as indicated by stippling on the leaves (fig. 11). As predatory mites will provide suitable control only if introduced before two-spotted spider mite

Fig. 13: Adult predatory mite.

numbers become high, they should be introduced at the first sign of damage. If the numbers of two-spotted spider mites build up before predators are released, a safe knock-back spray should be used.

Plants should be checked regularly to determine if the predators have become established. A 10-power hand magnifier lens is useful for predator identification.

Within four weeks the predatory mites should have stopped the spread of the two-spotted spider mites, and by five to eight weeks should have eliminated the initial infestation with no further plant damage.

Subsequent outbreaks, often occurring near doors, windows and support posts, may necessitate further introductions or transfer of predators from other areas within the greenhouse.

If, despite the application of predators, two-spotted spider mites continue to cause damage, certain chemical sprays can be used to kill the pest mites while leaving some of the predatory mites alive. Minimal spot spraying will usually correct an imbalance. See Table I for a suitable chemical.

Predatory mites are distributed to growers on leaf pieces (from beans) or in vermiculite. Each leaf piece has at least two predators. Predators in vermiculite are supplied in plastic "shaker" containers, each containing a specified number of predators, from which they are shaken on to a leaf (fig. 14). Most containers are designed to provide one predator per

Fig. 14: Applying predatory mites from bran-filled container.

shake. To ensure the mites remain healthy they should be kept cool until delivered to the grower and refrigerated until applied. During application, the container should be gently rotated to distribute the mites evenly in the vermiculite.

Application rates are:

Cucumbers

First, apply throughout the greenhouse by placing two or more predators on each leaf showing damage and on every second undamaged plant. Subsequently, treat spot outbreaks by applying two predators per damaged leaf.

Tomatoes

Predatory mites are less effective on tomatoes because the hairy stems tend to slow the movement of predators between leaves. Therefore, if predators are used on tomatoes they must be applied at a rate of two predators to every damaged leaf.

Ornamental and Tropicals

Apply two predators to each leaf showing signs of mite feeding, and six predators to each undamaged plant. Treat subsequent spot outbreaks with two predators per damaged leaf.

Thrips

Two species of thrips commonly attack greenhouse vegetable crops. These are the western flower thrips *Frankliniella occidentalis*, and the onion thrips *Thrips tabaci*. The western flower thrips is the more serious pest as it is not readily controlled by insecticides, necessitating the use of biological control techniques. The onion thrips, however, is readily controlled by chemicals, so biological control becomes optional.

Both species are known to feed on more than 100 plant species. Adults and immatures feed by puncturing the leaf surface and imbibing plant sap from the broken cells under the epidermis. This causes characteristic elongated silvery wounds on the leaf. A distinguishing feature from similar appearing mite damage is that the damage caused by thrips is surrounded by small black droplets of excreta.

Thrips are most commonly pests of cucumber and pepper, although they also occasionally attack tomatoes. On cucumbers the lower leaves are usually attacked first. On peppers, the first damage is usually on the youngest, uppermost leaves. On cucumber and pepper, heavy infestations will reduce plant vigor and yield and feeding on fruit of both crops will reduce quality. On tomato, infestations are generally restricted to the lower portions of the plants and rarely spread to the growing tip. Tomato fruit may also be attacked. Tomato spotted wilt virus, vectored by thrips is a threat to tomato and pepper crops in some locations.

The life cycles of both species of thrips are similar, and only that of the western flower thrips is presented here. The egg is inserted into the leaf and hatches in five days at 22° C. The nymphal stages feed for 8 to 10 days, then drop from the plant to pupate on the ground. Pupae remain in sequestered sites on the greenhouse floor for 7 to 10 days. The overall life cycle takes approximately 20 days at 22° C, more at lower temperatures and less at higher temperatures. When the pupa become adults, they fly to the upper portions of the plant and begin to lay eggs after one to two days. A female will lay from 6 to 10 eggs per day over a four to five week period, spending a great deal of time in the blossoms.

When the crop is removed from the greenhouse and the heat turned off, it is felt the adult thrips migrate to cracks and crevices in the structure where they remain until the heat is turned back on. In the spring and summer thrips may also invade greenhouses through the vents from populations on wild plants outside the greenhouses.

The predatory mite *Amblyseius cucumeris* (fig. 15) is used to control thrips. Adults are about one-half the size of *Phytoseiulus persimilis* used to control the two-spotted spider mite, and are a pale brown in colour.

A. cucumeris reproduce best at 20 to 25° C and above 70% RH. Females lay from one to two ovoid eggs per day over a 10 to 20 day life span. These hatch in one to two days and pass through three immature stages in 10 days at 20° C. Unlike the two-spotted mite predator, *A. cucumeris* does not eliminate its prey from the greenhouse. The mites kill only the first instar thrip. Second instar and adult thrips are able to defend themselves against mite attacks because of their comparatively large size. Adult mites can kill and consume from three to six first instars per day. Because of this relatively low predation rate, large numbers of *A. cucumeris* must be introduced to effect control. The predator is sensitive to day length and humidity. At short day lengths, around 12 to 13 hours of daylight, the predator enters reproductive diapause and ceases to lay eggs. It is not known if supplementary lights can alleviate this situation, but this characteristic may restrict the use of *A. cucumeris* early in the season. There is considerable egg mortality at low humidities and therefore the greenhouse should be maintained at high humidity when *A. cucumeris* are being applied.

Another predator developed as a thrips biological control agent is the minute pirate bug, *Orius*

Fig. 15: Predatory mite feeding on thrips nymph.

tristicolor. Unlike the predatory mite, this predator feeds on all thrips stages and will enter blossoms in search of thrips.

Both the nymphal and adult pirate bugs are predatory. The nymphs are amber to dark brown, and the adults about 3 mm long and flattened, have black and white markings (fig. 16). They will also attack spider mites, small aphids and caterpillars. These predators have a rapid growth rate, with development from egg to adult as short as 20 days.

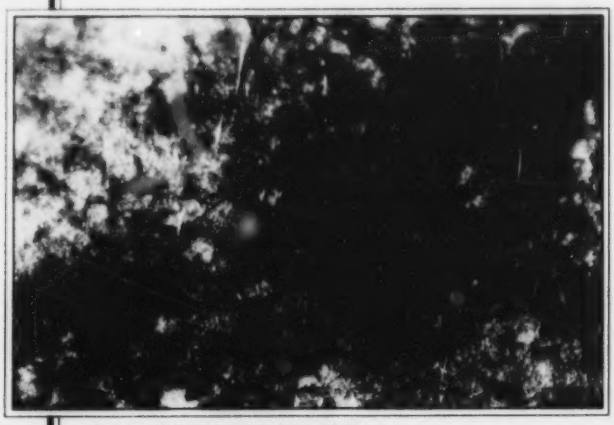

Fig. 16: Minute pirate bug adult.

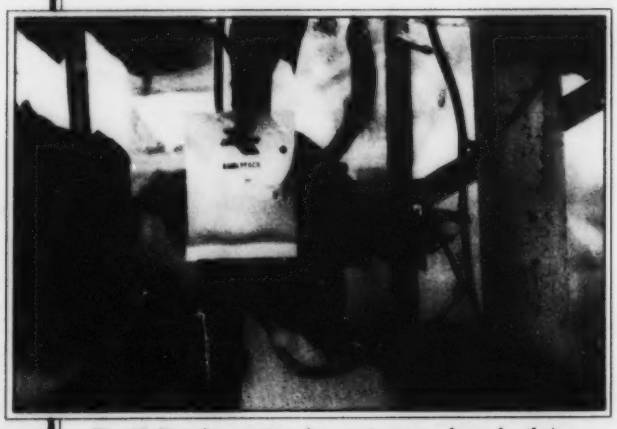

Fig. 17: Bran bag system for continuous release for thrips predatory mites.

Applying Thrips Predators

Predatory Mites

During the first month of the growing season when the plants are small, growers should look carefully for thrips damage. Monitoring with blue or yellow sticky traps at this time will help detect early thrips invasions. Alternately, if the greenhouse has a history of chronic thrips problems, the grower may begin introductions of *A. cucumeris* as soon as the plants have their first true leaves. It is important that the thrips be identified by a qualified person as the control strategy as the western flower thrips and other thrips may differ.

Predatory mites will provide adequate control only if introduced before thrips reach damaging levels. Plants should be checked regularly to verify establishment of predators. A 10-power hand lens may be used for this purpose by experienced growers. More accurate counts may be obtained by contracting the services of a pest management consulting firm. These firms use leaf-washing techniques and microscope counts to provide an accurate assessment of thrips and predator populations. Ideally, the numbers of predators should increase until they are equal to the number of thrips in the leaf wash samples. At this point, the thrips population is stable and should not increase further although damage may continue to occur for a while from the existing thrips.

Because it is often difficult to establish predators before March, growers should take steps to avoid early thrips infestations. A thorough season-end clean up will help accomplish this.

Amblyseius cucumeris are shipped to growers in the bran in which they are reared. The bran also contains grain mites, which is the food of the predators. Although the grain mites may be visible when the bran is applied to leaves, they do not damage plants. Predatory mites are available in two forms. They may be purchased in containers of several thousand predators in bran, or in small bags of a few hundred predators in bran. The large containers are used to shake predator-containing bran on to thrips infested leaves (fig. 14). The bags are attached intact to plants (fig. 17). Care must be taken to secure the bags to the plants so they won't be dislodged while the crop is being tended. The predators leave the bags from small, specifically sized openings made at the time of application. This system is designed to provide continuous releases of *A. cucumeris* over several weeks. The bags may also provide some protection from sprays and fumigants.

Containers of predators should be kept cool, but not frozen, until applied. Predators should be applied within 24 hours of receipt.

If properly applied, *Amblyseius cucumeris* introduced in the spring will normally provide control of western flower thrips by late June or early July. This will be evident by a stable thrips population, and by the predatory mites being at least as abundant as the thrips nymphs. If this is not the case, the biological control may be failing. If thrips damage becomes common with fruit, or new foliage extensively damaged, the thrips populations are too high and, if this is common over the entire planting, alternative control measures should be used.

Pirate Bugs

Pirate bugs are sensitive to day length, discontinuing egg laying at less than 12 hours light per day. Therefore pirate bugs are most effective after March. Pirate bugs are shipped as adults, with a food source in the container. They should be kept cool, but not frozen, until applied. To apply, open the container in an area of the greenhouse that contains thrips, gently shaking out the packing material. The adults fly and will readily disperse and locate thrips.

Pirate bugs are effective at low densities, and therefore can be difficult to find even when effective thrips control is established. However, nymphs and adults are often found on stems and in growing tips along the trellis wire. On peppers, both stages may be found in blossoms. In a cucumber thrips infestation, if one to two pirate bugs can be found on each plant, the outbreak should be brought under control within two weeks.

Application rates:

Predatory mites

Cucumber — introduce 20 predators per plant per week, for 10 weeks or until monitoring shows 1 predator for every 2 thrips on the leaves.

or

hang 1 controlled release bag on every third plant at 3 week intervals.

Peppers — introduce 2 predators per plant per week, for 10 weeks or until monitoring shows 1 predator for every 2 thrips on the leaves.

Pirate bugs

Cucumber & peppers — introduce 1 pirate bug per 1 - 2 plants in March. Usually one release at this rate, or several releases totalling this amount are needed to control moderate thrips infestations within 3 - 5 weeks.

Aphids

Aphids are a common problem on greenhouse peppers, and an occasional problem on cucumbers. A number of aphid species attack greenhouse crops, but the most serious are the green peach aphid *Myzus persicae* and the melon aphid *Aphis gossypii*. Green peach aphids are 1 to 3 mm long, usually green but sometimes pink or pale yellow. Melon aphids are about the same size and vary in colour from greenish, yellowish, or mottled to blackish (fig. 18). They can be distinguished from most other aphids by their short, dark cornicles, the pair of tubes near the back end of the body. Females give birth to one to five live young each day and these in turn are capable of producing offspring in less than a week at greenhouse temperatures. It is this high reproductive capacity that makes aphids difficult to control. Aphids pierce plant tissue and suck the plant sap, usually on undersides of leaves and in growing tips. They damage crops by secreting honeydew onto the leaves and fruit below, which allows a black fungus to grow on the surface of the fruit. Such fruit must be washed or wiped before it is sold. Severe aphid infestations also distort and suppress plant growth, and there is the risk that aphids from outdoor fields may spread virus diseases. Pesticide resistant races of aphids frequently occur.

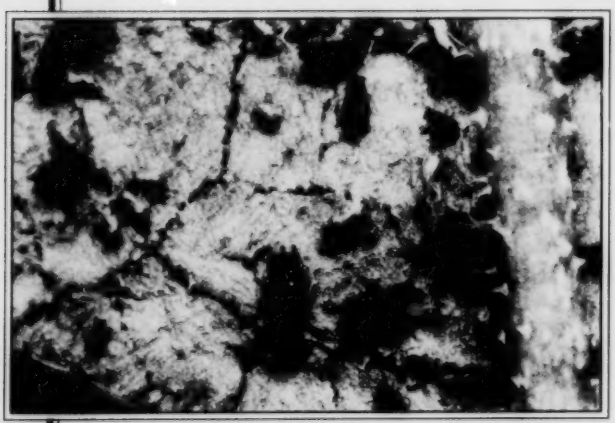

Fig. 18: Melon aphids.

The aphid midge, *Aphidoletes aphidimyza* can control aphids on greenhouse crops. It is a small, delicate insect, less than 2 mm long whose larvae are known to eat over 60 species of aphids. Females are active at night, searching for aphids and laying up to 250 eggs over their 10 day lifespan. Eggs are smooth, oblong orange capsules and are laid singly or in small groups near aphids. Eggs hatch in two to three days and the small orange larvae (fig. 19) immediately attack the aphids around them by injecting a paralyzing toxin, then suck them dry. When aphid populations are high, larvae may kill many more aphids than they eat. Larvae complete development in four to seven days, depending on temperature, then drop to the floor and burrow 2 - 4 cm into the soil or growing medium to pupate. Adults emerge from the pupae in two weeks. The complete cycle takes three to four weeks at greenhouse temperatures.

Biological control of aphids in sweet peppers works best if aphid parasites *Aphidius matricariae* are also released in the greenhouse to complement the activity of the midges. During the summer, these parasites commonly enter greenhouses from outdoors, but during the winter, they should be obtained from commercial suppliers. They are tiny, black parasitic wasps, less than 2 mm long, that lay eggs inside

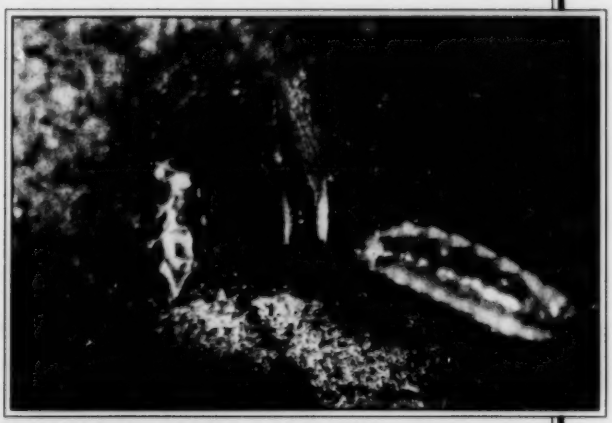

Fig. 19: Midge larva feeding on adult aphid.

aphids. As the wasp larva develops inside, it kills the aphid and then uses the mummified aphid as its pupal case. The rigid, light brown or bronze aphid mummies show up on leaves 7 to 10 days after the aphids are parasitized and adults emerge in five days by chewing an exit hole in the mummy.

Aphid populations can increase by 12 fold per week, so it is necessary to release predators and parasites while aphid populations are low. Lower leaves of young plants are usually attacked first and should be checked weekly from the time plants are set out. Aphid populations are usually unevenly distributed,

with a few infested plants in a small area while others in the same greenhouse are clean. Aphid midges and parasites will find and lay eggs in such infestations. However, if more than 10% of plants are heavily infested, non-residual sprays or fumigants should be used to decrease aphid populations. (Note: Pyrethroid residues repel aphid midges for at least three weeks after application).

Greenhouses with soil beds or with grow bags placed directly on gravel floors have the best success with biological control of aphids, probably because midge larvae find suitable sites for pupation on the floor. If the greenhouse floor is covered with plastic, it is better to use open-topped bags of growing medium rather than closed bags and to spread a thin layer of sawdust over the plastic between the rows, or cut "windows" in the plastic beside the bags to expose the soil below. Biological control of aphids will work without good pupation sites on the floor, but because fewer offspring of the midges survive, weekly releases of midges may be necessary throughout the season.

After September 1st, a steadily increasing proportion of the midges in the greenhouse will diapause (the insect equivalent of hibernation) in response to the shorter days. If aphids are a problem in the fall or winter release *Aphidius*, which do not usually diapause in greenhouses, or make weekly releases of midges or use chemical controls. During winter months (through late February), prevent midge larvae from diapausing by leaving lights on at night. Larvae are very sensitive to lowlight levels so a few incandescent bulbs left on along walkways are sufficient.

One 60-W bulb will prevent diapause in more than half of the larvae within a 20 m diameter circle, and a 100-W light will be effective over a 22 m circle. This is effective when plants are small or low-growing but has little effect in late fall in a mature pepper crop when plants reach to the overhead wires because light does not penetrate between the rows.

Aphids that have been attacked and paralyzed but not eaten can be mistaken for live aphids. Close examination under magnification is necessary to distinguish these. Midge eggs and older larvae are easy to see with a hand lens, but very young larvae are extremely difficult to find because they are light coloured and are often hidden by the aphids they are feeding upon.

Aphid midges are shipped as pupae in moist vermiculite. Upon receipt of the containers, sprinkle the vermiculite carrying the cocoons on the moist soil or root media in the shade under the plants. Product packaging is continually under development, therefore follow instructions on label.

IMPORTANT: Midges will not emerge from cocoons that fall on dry areas exposed to direct sun.

Application rates:

Young plants: (Dec. to early March)
- 1 midge per 2 plants weekly for 2- 4 weeks and 500 -2000 parasites per acre (0.5 ha).

Mid-season fruiting plants: (March to August)
- 1-2 midges per plant weekly for 2-4 weeks

Late-season: (September onwards)
- 1 midge per plant weekly and 500 -200 parasites per acre (0.5 ha).

When the picking zone has reached the middle of the plant, more aphids can be tolerated on the lower leaves because honeydew does not accumulate on fruit. This benefits the predator populations, which will build up quickly on the good supply of aphids.

Lady Beetles

Lady beetles feed on aphids and other small soft insects. The commercially available species is *Hippodamia convergens*, the convergent lady beetle (fig. 20). A single convergent lady beetle female may consume over 2,000 aphids and lay 1,500 eggs during its life span.

In greenhouses, after consuming many aphids the adult beetles often fly to the vents and leave the structure to lay eggs outdoors. It is difficult to establish an ongoing population of lady beetles in a greenhouse, so repeated releases are necessary. Lady beetles are not efficient predators at low pest levels. Therefore, they are most efficiently used to reduce high aphid populations to levels that can be further reduced by other biological agents such as predatory midges and parasitic wasps. Recommended lady beetle release rates are: an initial release of 5 gallons per hectare, with subsequent releases of 2 gallons per hectare at 4 week intervals.

Fig. 20: The convergent lady beetle, an aphid predator.

Fungus Gnats

Fungus gnats are common inhabitants of greenhouses. Usually they are not a problem, as the larvae feed on natural fungi and decaying organic matter in the soil. However, occasionally the larvae feed on roots and root hairs, thereby reducing growth and providing access for root pathogens. Small seedlings may be killed. As well, large numbers of adult fungus gnats can be annoying to workers.

Fungus gnat larvae are legless white maggots with a prominent black head. The oldest larvae are about 6 mm long. The adults are slender dark flies about 3 mm in length (fig. 21). They run rapidly over the soil and pots. Fungus gnats can be distinguished from other common greenhouse flies by their long thread-like antennae. Fungus gnats require wet conditions. The females lay up to 200 eggs in moist soil or other growing media. The life cycle takes 15 to 20 days to complete at normal greenhouse temperatures.

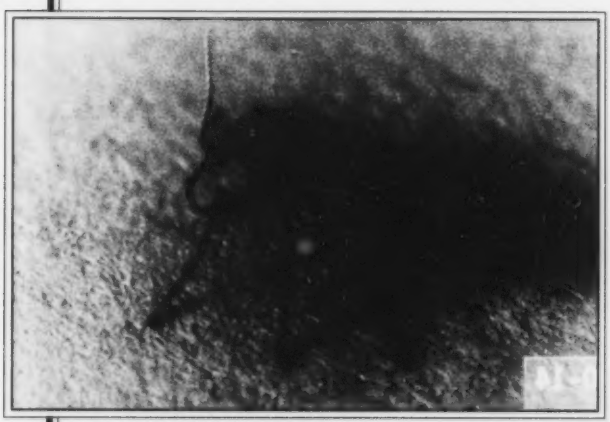

Fig. 21: Adult fungus gnat.

Biological control:

There are three biological agents for fungus gnat control: a predatory mite, a nematode, and a bacteria.

Predatory mites
(Geolaelaps [= Hypoaspis] sp.)

These tiny (0.5 mm long) brown mites feed on fungus gnat eggs and small larvae. The mites' life cycle is completed in about 10 days on the surface and upper 2 cm of soil.

The mites are sold in one litre containers of moist, sterile peat and vermiculite and are applied by shaking the mite-containing material on the surface of the growing media. One application early in the season may be sufficient to provide season-long control. Although there is some movement of these mites between plants, thorough coverage is important and every second plant should be treated. One litre will treat 500 to 1000 plants. Less will be needed if the mites are released while plants are close together in the propagating house.

Application rates for young plants when set out in the greenhouse are:

a) cucumbers - 4 to 8 litres per 0.5 hectare
b) tomatoes and peppers - 10 to 12 litres per 0.5 hectare

Nematodes

An insect parasitizing nematode *Steinernema carpocapsae* is available for fungus gnat control. The nematodes enter openings in the body of the insect larvae. As they feed and develop, the nematodes release bacteria that kill the insect host, usually within 28 to 48 hours. It appears the nematodes may not produce new infective nematodes, so further applications at 10 to 14 day intervals may be needed. When purchased, these nematodes, which never feed on plants, are incorporated into a gel to which water is added to activate them. Once mixed, the nematodes must be applied either as a drench or a spray to moist soil within two to three hours. Application rates depend on the concentration of nematodes in the product, so label recommendations should be followed.

Bacteria

A bacteria *Bacillus thuringiensis israeliensis*, lethal to the immature stages of fungus gnats and many other flies, has been developed and is commercially available in many countries. Upon ingestion the bacteria produces a toxin that kills the host larva within 48 hours. The ingested bacteria do not produce new infective bacteria, so repeated applications may be necessary. This may be determined by monitoring adult gnats with yellow sticky traps.

The bacteria, which do not affect adult gnats, are purchased as a concentrated suspension which is mixed with water and applied as a soil drench or high volume spray. The top 2 to 3 cm should be thoroughly wetted. The dilution and application rates depend on the potency (International Toxicity Units per mg) of the formulation obtained, so label recommendations should be followed.

CROP MANAGEMENT

Delaying the occurrence of pests in greenhouse crops until later in the growing season often increases the probability of biological controls succeeding. Many of the biological agents are sensitive to day length and temperature, with reproduction stopping or slowing during winter months. Hence, an effective season-end clean up of the previous crop is important in eliminating pests that could quickly infest the next crop. Also, all plants being brought into the greenhouse should be examined for pests. Avoid starting new plants in a greenhouse with an existing crop.

During the summer months pests may breed on plants outside the greenhouse and later enter it. This can be avoided or delayed by establishing, with a non-specific herbicide, a 5 to 10 m plant-free strip around the greenhouse. A well-mowed lawn will also serve this purpose. Screening of vents with materials manufactured for this purpose presents a barrier to invading pests. Visitors that may be carrying pests from a previously-visited greenhouse should be discouraged from entering the crop.

Leaves pruned from plants should be examined for the presence of biological agents, especially predatory mites and parasitized (black) scales, before they are removed from the greenhouse. If black scales are present, the leaves should be left at the base of the plant for about a week to allow the adult parasites to emerge. Emergence can be determined by examining the scales for a small round hole (fig. 8), easily seen with a 10-power magnification hand lens. Pruned leaves with predatory mites should be placed intact or in pieces, depending on the number of predators, on other pest-infested plants. Once the biological agents have become established in one area of the greenhouse, growers can actively move them on leaves to other parts of the crop where they may be needed.

USE OF CHEMICALS

Chemical pesticides may be required occasionally to augment the biological agents or to control pests for which no biological agents are available. When this is necessary, materials should be selected that are minimally toxic to the biological agents, and they should be applied in a manner that will be least hazardous to the parasites and predators.

If pest numbers develop to damaging levels in isolated areas, only these areas should be treated. In this way, predators and parasites in other locations are not exposed to pesticides.

During prolonged periods of hot, dry, summer weather, predatory mites tend to avoid the uppermost leaves and consequently two-spotted spider mite infestations may develop there. When this occurs, only the tops of plants should be treated and the lower parts left untreated to preserve the predators. Similarly, whitefly adults are usually most abundant on the uppermost leaves of plants while the majority of *Encarsia formosa* adults occur below this level as they search the older leaves for immature whiteflies. Therefore, whitefly populations can by reduced without destroying all the parasites by carefully spraying only the tops of the plants. Thrips drop to the greenhouse floor for part of their life cycle. Consequently, some control can be attained without jeopardizing the predator mites on the plants by spraying the floor area below infested plants.

Similarly, fungus gnat adults tend to walk over the soil and growing bags so a surface spray of these will assist in control with minimal damage to biological agents.

The effect of specific pesticides on biological agents is given in Table I.

TABLE I: Short term Toxicity of Insecticides, Fungicides, and Growth Regulators to Bio-control Agents

L - low M - moderate H - high - unknown

Insecticides		Encarsia immatures	Encarsia adults	Predatory mites	Aphidoletes aphidimyza	Nematodes	Pirate Bugs
Ambush	SP	H	H	H	H	-	H
Decis	SP	H	H	H	H	-	H
Diazinon	SP	H	H	M	H	L	H
	Dr	L	M	L	-	-	-
Dibrom	SP	M	H	M	-	-	-
Dichlorvos	F	H	H	H	H	H	-
Dipel	SP	L	L	L	L	L	-
Dursban	SP	H	H	H	H	H	-
Enstar	SP	-	L	L	-	-	-
InsectSoap	Sp	M	H	M	M	-	M
Kelthane	SP	L	M	H	M	-	-
Lannate	SP	H	H	H	H	-	-
Malathion	SP	M	H	M	H	-	-
Nicotine	F	L	M	L	H	-	-
Oils	SP	L	H	M	L	-	-
Orthene	SP	H	H	H	H	L	-
Parathion	F	M	H	H	H	-	-
Pirimor	SP	L	M	L	H	-	M
Sulfotep	F	M	H	H	H	-	-
Thiodan	SP	L	H	M	H	-	M
Trumpet	SP	H	H	H	H	M	-
Vendex	SP	L	L	L	L	-	L
Spreader Stickers							
Agral 90		-	M	M	-	L	-
Fungicides							
Benlate	SP	L	L	H	L	L	L
Botran	SP	L	L	L	L	-	L
Captan	SP	L	L	L	L	-	-
Copper	SP	L	L	L	L	-	-
Karathane	SP	L	L	L	L	-	-
Maneb	SP	L	H	L	L	-	-
Manzate	SP	L	L	M	-	-	-
Rovral	SP	L	L	L	L	-	L
Sulpher	SP	L	L	L	L	-	L
Growth Regulators							
B-Nine	SP	L	L	L	-	-	-
Cycocel	SP	L	L	L	-	-	-

SP - Spray Dr - Drench F - fumes

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